Efficacy of FLOW 800 with Indocyanine Green Videoangiography for the Quantitative Assessment of Flow Dynamics in Cerebral Arteriovenous Malformation Surgery

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Key words
- Arteriovenous malformation
- FLOW 800
- Indocyanine green videoangiography
- Quantitative assessment

Abbreviations and Acronyms
AI: Arbitrary intensity
AVM: Arteriovenous malformation
DSA: Digital subtraction angiography
ICG: Indocyanine green
MVTT: Microhemodynamics microvascular transit time
T1/2 FI: Time to the half-maximum fluorescence intensity

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Citation: World Neurosurg. (2015) 83, 2:203-210. http://dx.doi.org/10.1016/j.wneu.2014.07.012

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

OBJECTIVE: **To evaluate the quantitative assessment of flow dynamics during surgery for arteriovenous malformations (AVMs) with FLOW 800 with indocyanine green videoangiography.**

METHODS: **Changes in flow dynamics in the superficial AVM components (feeder, nidus, and drainer), the adjacent cortical artery, and the cortical vein surrounding AVM were evaluated. Analysis was performed at predissection, postclipping of the feeders, and postresection of the nidus with the use of quantitative values of the maximum fluorescence intensity, time to half-maximum fluorescence intensity ($T_{1/2}$ FI), and the fluorescence intensity rate at $T_{1/2}$ FI semiautomatically obtained with the use of FLOW 800 software.**

RESULTS: **FLOW 800 assessments were performed in 7 cases. The time difference between the $T_{1/2}$ FI, defined as transit time, in the cortical artery and the drainer was prolonged from 0.08 $\pm$ 0.65 seconds to 2.63 $\pm$ 1.79 seconds ($P < 0.0001$) at postfeeder clipping phase. The transit time between the cortical artery and the cortical vein was reduced to 3.76 $\pm$ 1.37 seconds at post feeder clipping phase ($P = 0.024$) and 2.63 $\pm$ 0.80 seconds at final phase ($P = 0.005$) compared with 4.56 $\pm$ 1.47 seconds at predissection phase. The maximum intensity and the fluorescence intensity rate at $T_{1/2}$ FI were not significantly different at these phases, excluding the maximum intensity of the drainer decreasing from 533 $\pm$ 271 to 399 $\pm$ 217 ($P = 0.006$) at post feeder clipping phase.**

CONCLUSION: **FLOW 800 analysis with indocyanine green videoangiography provides the real-time hemodynamic status of the AVMs and adjacent brain at various stages of resection. This technique is feasible to resect AVMs more safely and convincingly.**

INTRODUCTION

The application of indocyanine green (ICG) videoangiography in cerebrovascular neurosurgery is practiced widely. Conventional ICG videoangiography is a real-time intraoperative imaging tool that helps identify the vascular architecture, flow direction, and qualitative blood flow transit speed. These features enable surgeons to intraoperatively distinguish between arteries and veins or between normal and abnormal vascular components such as a cerebral aneurysm, arteriovenous malformation (AVM), and dural arteriovenous fistula (11, 13, 18, 23, 25). Conventional ICG videoangiography also helps identify vessel patency during aneurysm clipping, intracranial-extracranial bypass, and carotid endarterectomy (8, 19, 23, 30); however, one drawback of this conventional technique is that a precise quantitative analysis of blood flow dynamics cannot be achieved. This analysis of blood flow is especially important during AVM surgery because a precise understanding of the vascular architecture and changes in flow dynamics help surgeons perform surgery in a safe and efficient fashion.

FLOW 800 software was developed as an additional analytical imaging tool to analyze blood flow dynamics with the use of ICG videoangiography. This technique enables an objective and quantitative analysis presented visually as a color map and ICG intensity-time curve. Previous studies reported the quantitative flow analysis in cerebrovascular surgery (14, 15, 17, 20, 24, 29); however, changes in flow dynamics via the use of time and fluorescence based parameters during AVM resection are not yet available in detail. In this study, the authors aimed to evaluate whether FLOW 800 analysis with repeated ICG videoangiography at various stages of resection for AVMs is useful for evaluating the hemodynamic changes in AVMs and adjacent brain. To analyze time and fluorescence based parameters, we used quantitative values semiautomatically obtained by applied FLOW 800 software.

PATIENTS AND METHODS

This study population included 7 patients (3 male, mean age: 33.3 years, range: 9–64 years) who underwent resection of cerebral AVMs between January 2010 and March 2012. Three patients presented with seizures and intracerebral hemorrhages. AVM was incidentally diagnosed in 1 patient. Spetzler-Martin grade I AVM was identified in 2 patients, grade II in 4 patients, and grade III in 1 patient (Table 1).

Table 1. Patients Characteristics

Case	Age (y)/ Sex	AVM Location	S&M Grade	Presentation	Location of Nidus	Maximum Size of Nidus, mm	ICG Injection, Times	Intra- or Postoperative DSA
1	27/F	Lt. parietal	2	Hemorrhage	Superficial	28	5	Yes
2	29/F	Lt. temporal	2	Seizure	Superficial	19	5	Yes
3	34/F	Rt. insula	1	Hemorrhage	Deep	10	5	Yes
4	9/F	Lt. parietal	3	Seizure	Deep	22	5	Yes
5	36/M	Lt. temporal	2	Seizure	Deep	20	6	Yes
6	34/M	Rt. frontal	2	Incidental	Superficial	42	4	Yes
7	64/M	Rt. cerebellum	1	Hemorrhage	Superficial	8	3	Yes

Deep means that nidus is covered by parenchyma and superficial means that nidus faces on the surface of the parenchyma.
AVM, arteriovenous malformation; S&M, Spetzler and Martin; ICG, indocyanine green; DSA, digital subtraction angiography; F, female; M, male.

Three patients with deep feeders, which were considered difficult to detect in the superficial operative field, underwent preoperative embolization using N-butyl-2-cyanoacrylate. To detect residual AVMs, intraoperative digital subtraction angiography (DSA) was performed in 2 cases and postoperative DSA in 5 cases.

ICG Videoangiography

After intravenous bolus injection of ICG, the operative field was illuminated by the use of a microscope-integrated light source with a wavelength covering the ICG absorption band (range, 700–850 nm; maximum, 805 nm). Arterial, capillary, and venous flow images were observed on the video screen in real time. The recommended dose of ICG for this type of videoangiography is 0.2–0.5 mg/kg. In this study, all patients received an ICG injection at a dose of 0.1 mg/kg as a bolus. This dose is sufficient for analysis and enables us to perform repeated ICG videoangiography at least 5–10 minutes after the last injection. All images were recorded using the microscopic hardware and could be confirmed easily, immediately, and repeatedly. All operations were performed using OPMI Pentero (Carl Zeiss Co., Oberkochen, Germany).

TIMING OF ICG VIDEOANGIOGRAPHY

Intraoperative ICG videoangiography was first performed immediately after the dura was opened to analyze baseline flow dynamics of the normal vascular architecture and superficial AVM components. ICG videoangiography was sequentially performed to evaluate the flow reduction of the nidus and drainer after the main feeders were occluded by stepwise clipping of the feeders. Finally, ICG videoangiography was performed after total resection of the nidus.

FLOW 800 Functions

For additionally evaluating blood flow dynamics, a FLOW 800 function was installed in the Pentero microscope. Temporal fluorescence projection uses colors, defined as a color map that allows us to instantly identify the direction and sequence of blood flow. The target vessel is shown as a continuous color scale, depending on the time it takes to reach the ICG dye. Red represents the initial blood inflow, followed by a gradient color scale in blue for the subsequent blood flow sequence. Another map uses different shades of gray based on the maximum fluorescence intensity, which was used for the quantitative analysis of vascular flow dynamics with an ICG intensity-time curve.

Management of the Quantitative Analysis of Vascular Flow Dynamics by FLOW 800

Quantitative analysis of vascular flow dynamics was performed as follows: In 1 session, maximum 8 regions of interest (ROIs) were set on a superficial target vessel on the maximum intensity map. Fluorescence intensities were measured in arbitrary intensity units (AIs). Each ICG intensity-time curve and the complementary quantitative values of the time to the half-maximum fluorescence intensity ($T_{1/2}$ FI [seconds(s)]) from the start of the ICG analysis, maximum intensity (AI), and fluorescence rate at $T_{1/2}$ FI (AI/s) were semiautomatically obtained in the same screen, $T_{1/2}$ FI as "Delay" and fluorescence rate at $T_{1/2}$ FI as "Slope". The $T_{1/2}$ FI by itself has no meaning because the timing taken to start the ICG analysis was not consistent; however, to assess transit time, defined as the time difference between the $T_{1/2}$ FI in 2 points in the same phase, we evaluated the blood flow dynamics changes in each vascular component. The ROIs were set on the superficial AVM components (main feeders, nidus, and main drainers), cortical artery, and cortical vein adjacent to the AVM. On preoperative DSA, we confirmed that the adjacent cortical artery and the vein surrounding the AVM in the operative field were not associated directly with the AVM.

The ROIs of the main feeders and drainers were evaluated at 2 points in some patients when the area of perfusion was apparently different. The ROIs of the cortical artery and vein were evaluated at 1 point in each patient. The total number of evaluated ROIs for the main feeders was 10 (2 points for each case 1, 4, and 5; 1 point for each case 2, 3, 6, and 7), for the nidus was 4 points (1 point for each case 1, 3, 6, and 7), and for the main drainer was 11 points (2 points for each case 1, 2, 5, and 6; 1 point for each case 3, 4, and 7). In 3 patients with a deep-seated nidus, the ROIs could not be set on the nidus because it was covered with parenchyma. The ROIs in each situation were set on the same point. FLOW 800 analysis was performed at the time of dural opening (baseline phase), after maximum flow